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Radiated Electric Field Measurements in U.S. Army Helicopters

By

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Biodynamics Research Division

February 1992

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United States Army Aeromedical Research Laboratory
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Aircraft systems and medical devices generate electromagnetic fields. Electromagnetic interference (EMI) can cause faulty operation of aircraft systems or medical devices and endanger patients or aircraft crewmembers. An in-flight study was conducted to describe the electromagnetic fields in typical operations with U.S. Army helicopters. Broadband isotropic field sensors measured electric fields from 5 kHz to 3 MHz, 3 to 500 MHz, and 0.5 MHz to 6 GHz. Fields were measured at 0.5 m intervals in JOH-58A, JUH-1H, and JUH-60A helicopters with systems off, operating RPM, 5-foot hover, 50-foot hover, and cruise.

Environment electric fields were homogeneous and less than 0.1 V/m. Helicopter fields increased during ascent, but remained less than 2 V/m except during radio transmissions. EMI was demonstrated during FM radio transmission on the Physio Control Lifepak® 8. The results are useful in evaluating electromagnetic emissions from medical devices and predicting operations that may result in in-flight malfunction of a medical device.

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Introduction

Aircraft systems and medical devices generate electromagnetic fields and are sensitive to interference from electrical fields found throughout the environment. The sudden failure or faulty operation of an aircraft system or medical device due to electromagnetic interference (EMI) can endanger the lives of patients or aircraft crewmembers.

This report describes a study to evaluate the electromagnetic fields found during typical operations in U.S. Army helicopters. This information can be used to identify operations and positions in the aircraft where interference between medical equipment and aircraft systems is likely to be encountered.

Background

The electromagnetic spectrum extends from the extremely short cosmic rays with wavelengths of 10^{-16} m to long radio waves that are several kilometers in length. The portion of the spectrum from 1 to 300 MHz shown in Figure 1 is of particular concern because this is the area of greatest sensitivity for aircraft wiring and medical equipment. Radio frequency noise is inefficiently received on a wire below 1 MHz and the induced voltages from noise above 300 MHz is reduced (Clarke, 1986).

Electromagnetic interference in aircraft comes from a variety of sources: (1) Transmitters of radio frequencies, including those on the aircraft for HF, UHF, or VHF communication and those on the ground for FM radio or VHF television broadcasts, (2) aircraft power line (400 Hz) electrical and magnetic fields, (3) computer and avionics timing and control circuits that generate radio frequencies of 1 MHz or higher, (4) aircraft power regulators, (5) electrical switching transients from turning on and off aircraft lights, fans, or flaps, and (6) electrostatic discharges including lightning. These transients and electromagnetic waves may transfer into wiring and cause electromagnetic interference to other aircraft systems or medical equipment used in the aircraft (Clarke, 1986).

Over 50 years ago, the U.S. Army discovered the ignition systems of military vehicles interfered with communication receivers and began setting standards for the measurement and suppression of electromagnetic interference. Currently, U.S. Government equipment for procurement is tested for electromagnetic compatibility in accordance with standards established by MIL-STD-461C, "Electromagnetic emission and susceptibility requirements for the control of electromagnetic interference" and MIL-STD-462, "Electromagnetic Interference Characteristics, Measurement of," (Bronaugh and Lambdin, 1988).

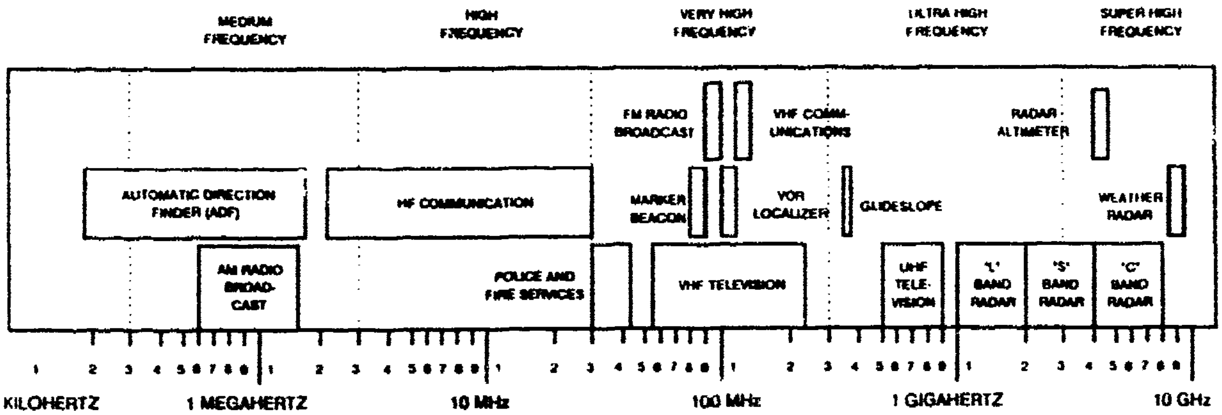


Figure 1. Electromagnetic frequency spectrum.

Another area of concern is the hazards of electromagnetic radiation to personnel (HERP). The rationale for determining the radio frequency (RF) limits for human exposure is based on the body heating effects. Research is being done to define the possible effects of low-level electrical fields on health. The current American National Standards Institute (ANSI) standard is based on the specific absorption rate (SAR), which is the rate of energy absorption per mass of tissue. The SAR depends on the density of the tissue, tissue conductivity, and magnitude of the electrical field in the tissue. The ANSI standard is based on an average SAR limit of 0.4 W/kg, which is 1/10 the value thought to be the threshold of adverse affects. The current military standard is the same as the ANSI limits with the exception of 5 mW/cm^2 relaxed level above 1 GHz for military operations. Electric fields usually are measured in milliwatts per centimeter square for human exposure studies and volts per meter for electromagnetic compatibility (EMC) work. Table 1 provides a rapid conversion scale where free space impedance is 377 ohms.

Table 1.

Conversion of field intensity measures.

mW/cm^2	V/m
1	61.4
2	86.8
5	137.3
10	194.2
20	274.5
100	614.0

A rough idea of the magnitude of these levels can be gained by comparing the energy of the sun's radiation at the earth's surface which is approximately 100 mW/cm^2 to the microwave radar on an aircraft carrier that produces electromagnetic fields of 26,500 mW/cm^2.

Energy that is dangerous to human health also can be detrimental to certain weapon systems and associated equipment. Radiated fields can cause dudding or premature actuation of sensitive electrically initiated explosive elements. Ordnance may be more sensitive than humans because there is no mechanism to dissipate internal heat among the electrical circuits. Operations that involve fuel handling near a transmitting antenna also may prove hazardous if an induced spark ignites the fuel-air mixture. As a result, RF field limits due to the Hazards of Electromagnetic Radiation to Ordnance (HERO) or Fuel (HERF) are lower than the human exposure limits. The ANSI human exposure limit and HERO limits are detailed in Figure 2 (Barge, 1989).

The U.S. Army program for testing and evaluation of equipment for aeromedical operations has been established to test and evaluate medical equipment for in-flight use aboard Army medical evacuation (MEDEVAC) and military assistance to safety and traffic (MAST) aircraft. Each medical device is evaluated to determine its compatibility and performance in various temperature, altitude, and humidity environments. In addition, the medical device is tested to determine its maximum levels of electromagnetic emissions and the minimum levels of electromagnetic interference to which the item is susceptible. Each item is also evaluated to discover human factors problems that may be exacerbated in aviation medical service (Mitchell and Adams, 1988).

This study was initiated to identify the actual electric field strengths typically encountered in U.S. Army helicopters during various modes of operation. This information will assist future in-flight evaluations of medical devices by clarifying flight profiles and aircraft systems where most EMI problems are likely to be encountered. Persons using medical equipment in MEDEVAC operations also may benefit by recognizing the conditions

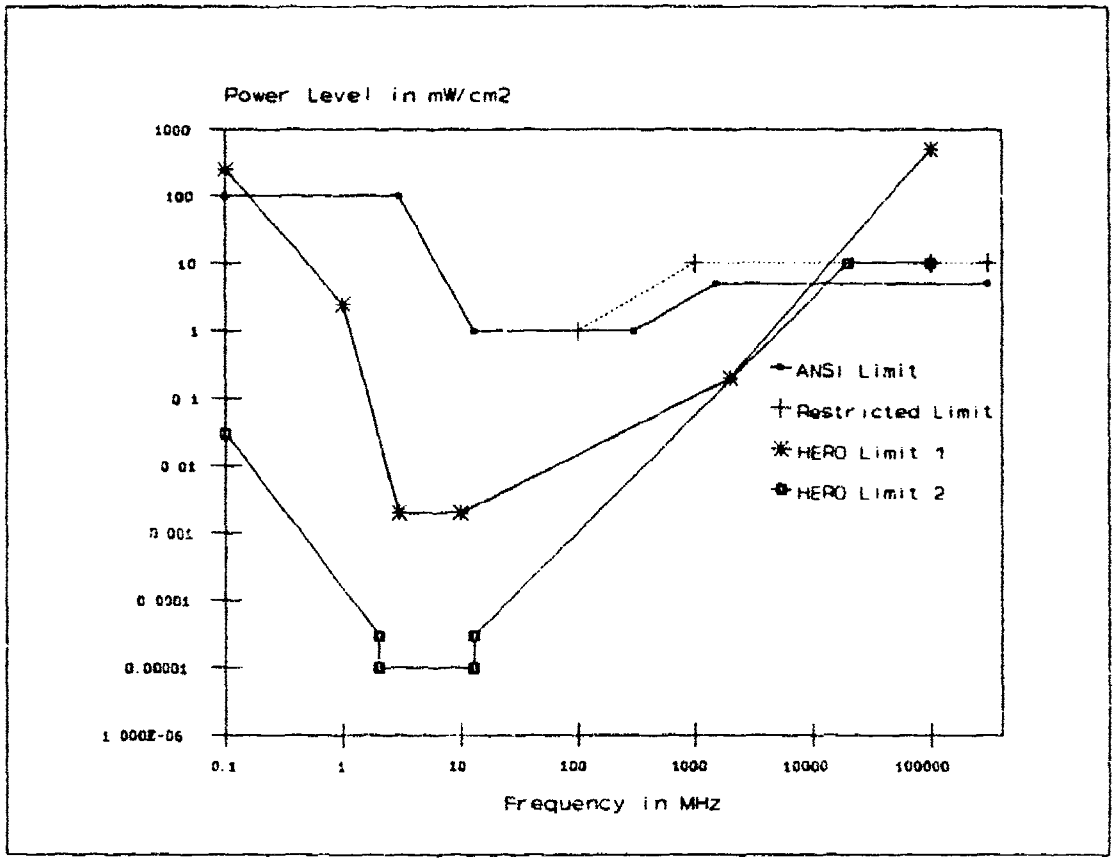


Figure 2. Comparison of health and HERO limits.

that contribute to electromagnetic interference and result in sudden failure of a medical device.

Materials and methods

Equipment

An Aeritalia electric and magnetic field sensor system, type SB08*, was used to measure broadband electric fields from 5 kHz to 500 MHz in two frequency bands. This system includes the Aeritalia model TE 307 monitor* and 19R1001-2 isotropic field sensor* used to measure electric field strength in the 5 kHz to 3 MHz frequency band and the TE 307 and 13R1001-1 isotropic field sensor used to measure electric field strength in the 3 to 500 MHz frequency band. A Holaday model HI-3001 Isotropic Broadband Field Strength Meter* was used with the red electric field probe to measure electric field strength from 0.5 MHz to 6 GHz.

* See Appendix B.

Environment grid

A tape measure and chalk were used to draw an 8 by 8 meter grid marked in 0.5 meter increments on the helipad at the U.S. Army Aeromedical Research Laboratory (USAARL), Fort Rucker, Alabama. Vertical increments from the ground to 2.5 meters height were judged by using a ladder and plumb line marked with 0.5-meter increments. Electric field strengths were measured using each of the three probe systems at each 0.5 meter horizontal and vertical point in the environment grid for the initial environment monitoring. Subsequent environment monitoring on the helipad was done with a 1 meter increment within the confines of the original 8 x 8 x 2.5 meter grid.

Aircraft grids

A 0.5 meter increment grid was drawn in the passenger compartment of the JOH-58A helicopter, SN 71-20778. The right front corner of the passenger seat was designated as the grid reference point and the front edge of the seat the horizontal reference line. Vertical increments of 0.5 meters yielded 33 data points in the passenger area of the JOH-58A helicopter. Figure 3 shows the grid drawn in the JOH-58A aircraft cabin oriented in the 8 x 8 m environment grid. Appendix A shows the aircraft equipment list at the time of testing.

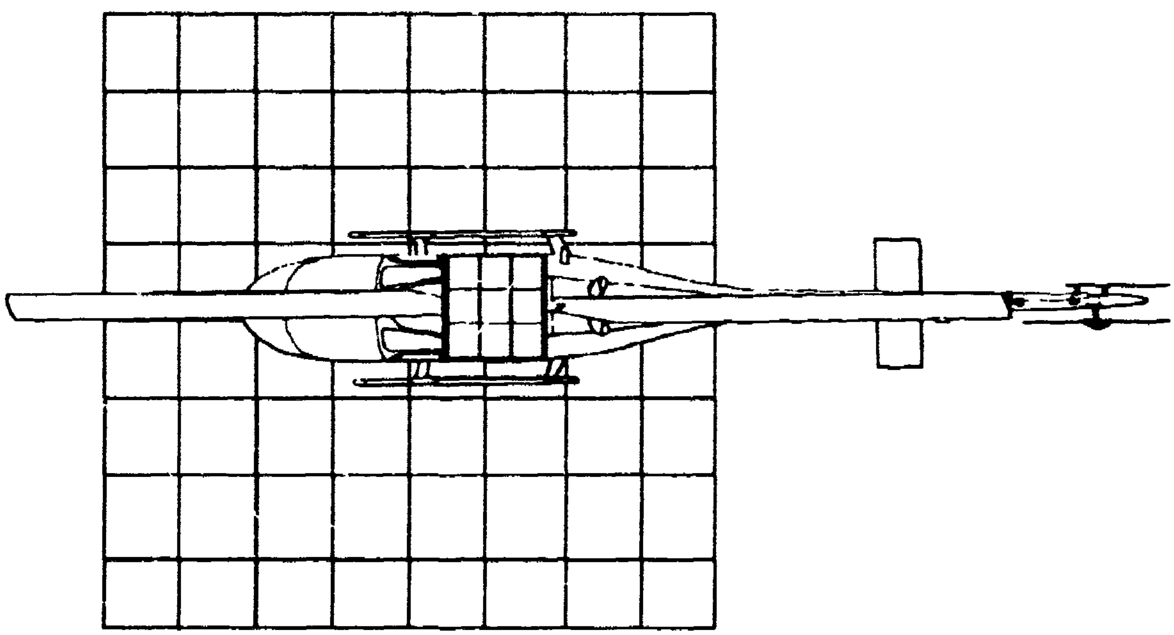


Figure 3. JOH-58A helicopter grid reference.

A 0.5 meter increment grid was drawn in the passenger compartment of the JUH-1H helicopter, SN 71-20033. The right front corner of the transmission housing at the floor was designated as the grid reference point and the front edge of the transmission the horizontal reference line. Vertical increments of 0.5 meters yielded 84 data points in the passenger area of the JUH-1H helicopter. Figure 4 shows the grid in the JUH-1H aircraft cabin oriented in the 8 x 8 m environment grid. Appendix A shows the aircraft equipment list at the time of testing.

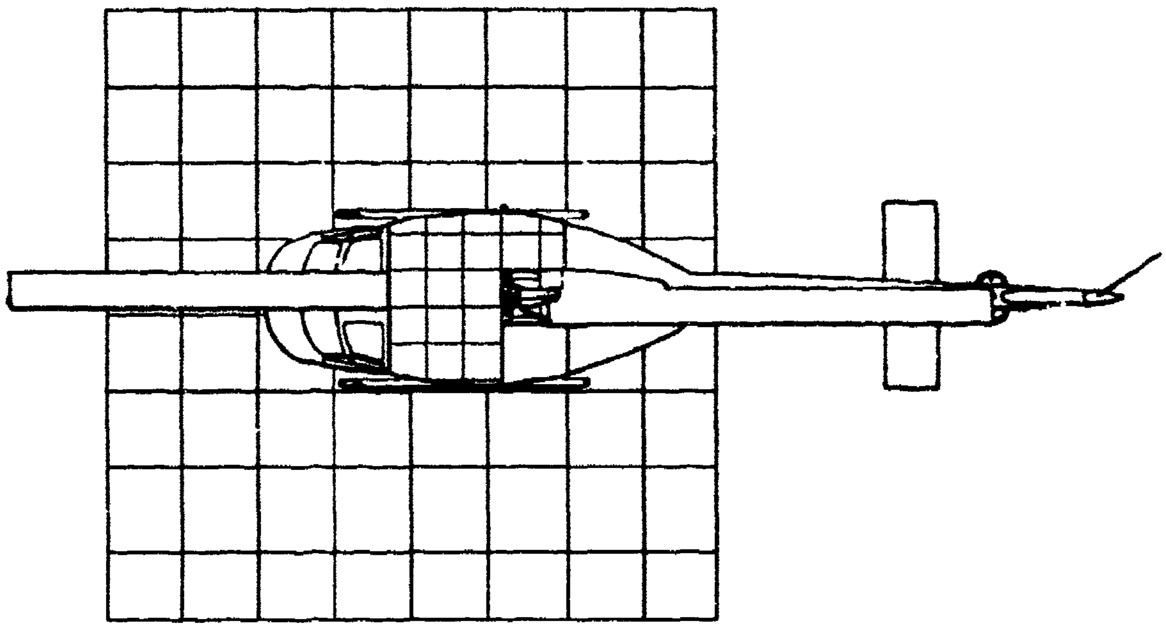


Figure 4. JUH-1H helicopter grid reference.

A 0.5 meter increment grid was drawn in the passenger compartment of the JUH-60A helicopter, SN 88-26069. The right rear corner of the cargo compartment was designated as the grid reference point and the back wall of the cargo area formed the horizontal reference line. The patient evacuation carousel in the fore-aft position prevented measurement along the aircraft midline. Vertical increments of 0.5 meters yielded 112 data points in the passenger area of the JUH-60A helicopter. Figure 5 shows the grid drawn in the JUH-60A aircraft cabin oriented in the 8 x 8 m environment grid. Appendix A shows the aircraft equipment list at the time of testing.

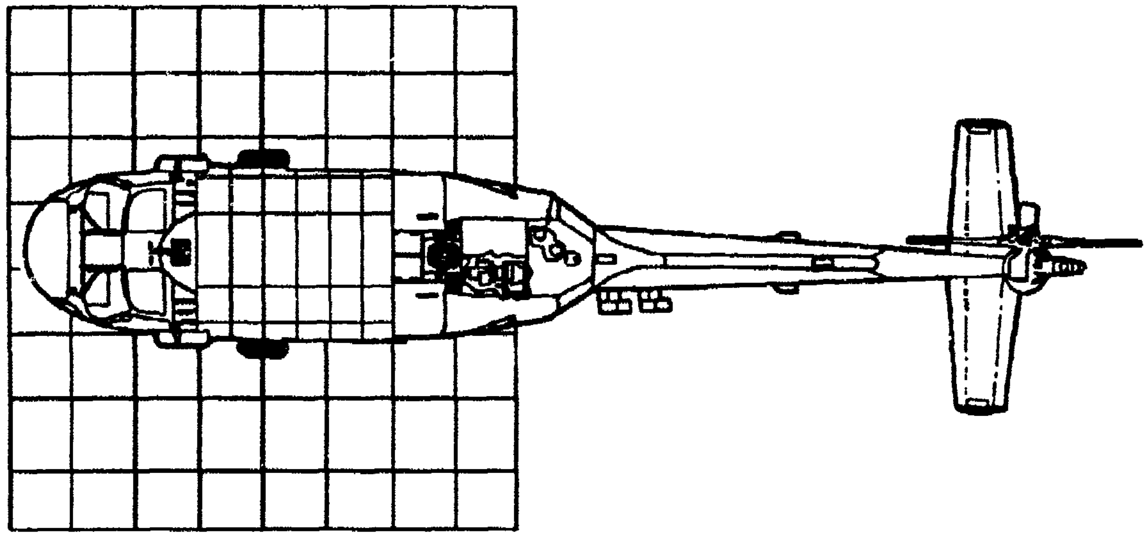


Figure 5. JUH-60A helicopter grid reference.

Phases of flight

The electric field strength at each data point was measured for each test aircraft in various modes of operation. These included sitting on the ground with the engine and all equipment turned off, sitting on the ground with navigation and communication equipment on, and operating rotor RPM, 5-foot hover, 50-foot hover, and cruise flight. A second flight was performed in the JUH-1H aircraft to determine the variability in measurements for the same aircraft on two different flights.

Power density errors

The ability of an electromagnetic field to cause a medical device to fail is determined by the power density in the field. The power flux flow or power density (P_D) is measured in watts per square meter and determined by the interaction of the electric field and magnetic field intensity.

$$P_D = E \times H$$

where,

E = electric field intensity in volts per meter
H = magnetic field intensity in amps per meter

The electric and magnetic field intensities are related by the wave impedance Z in ohms:

$$Z = E/H$$

For electromagnetic fields measured far from the radiation source, the electric and magnetic fields are related by 377 Ω. These fields are designated as far fields, but such a relation does not exist close to the object generating the fields. In the near field, the wave impedance is determined by both electric and magnetic fields. The power density in a high impedance field, such as a low current through a monopole antenna, is predominantly the electric field component. In a low impedance field, such as high current through an electric motor, the magnetic field component predominates and electric field strength measurements would be expected to underestimate the power density (Duff, 1988).

Results

The strength of the electric fields for the 5 kHz to 3 MHz band is presented for each aircraft and phase of flight in Figure 6. The electric fields measured in the 3 to 500 MHz band averaged less than .02 V/m in the JOH-58A helicopter and 0 for all phases of flight and locations within the JUH-1H and JUH-60A aircraft. No electric fields were detected with the 0.5 MHz to 6 GHz broadband receiver in the environment or during aircraft operations. All electric field measurements repeated during a second flight in the JUH-1H helicopter were within one standard deviation of the measurements recorded on the initial flight.

The environmental field strength did not change significantly among the different aircraft testing days as shown in Table 2. In addition, there was no specific area within the passenger compartment of any aircraft where greater than average electric field strengths were measured in each phase of flight.

Table 2.

Range of environment electric field strengths (5 kHz to 3 MHz).

Date	Average strength (V/m)	Standard deviation (V/m)
21 Aug 91	.075	.029
4 Sep 91	.078	.030
27 Sep 91	.069	.025

The strongest electric fields were measured when FM, UHF, or VHF transmitters were keyed. These frequently resulted in measurements exceeding the capacity of the sensor (>100 V/m) in the 5 kHz to 3 MHz band as detailed in Table 3.

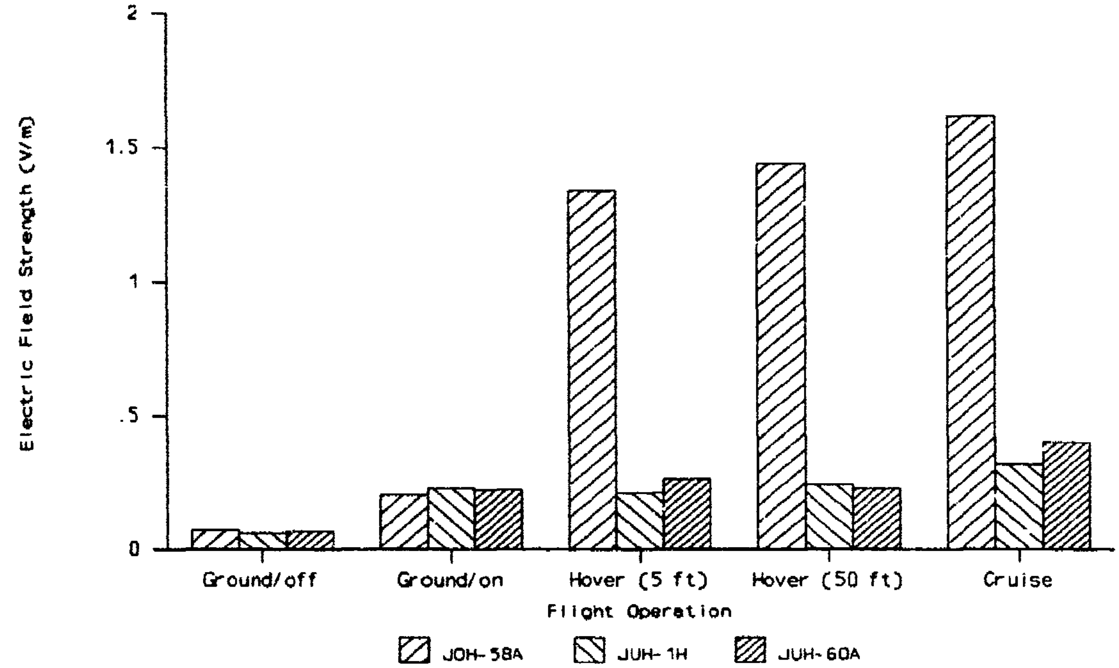


Figure 6. Measured electric field strength - 5 kHz to 3 MHz.

Table 3.

Electric field increase when transmitter keyed (V/m).

Radio	Aircraft	0.5 kHz-3 MHz	3-500 MHz
FM	JOH-58	0	0
	JUH-1H	0.2	1.2
	JUH-60	0	0
VHF	JOH-58	10.0	0.3
	JUH-1H	>100.0**	2.9
	JUH-60	.2	0
UHF	JOH-58	>100.0**	2.5
	JUH-1H	>100.0**	5.4
	JUH-60	>100.0**	1.0

** Measurement exceeds the maximum reading for the sensor.

Discussion

The electric fields encountered in the environment were very low and homogeneous among the days tested. This is consistent with rural levels of less than .1 V/m and much less than levels of 20 V/m described by Clarke (1986) near high power broadcast stations. By the year 2000, Larsen (1988) predicts that worst case environmental fields can reach 1000 V/m in the ultra-high frequency band.

The greatest electric fields measured in this study were present in the 5 kHz to 3 MHz range when the aircraft transmitters were keyed. The FM transmitters operate in the range of 30 to 75.95 MHz, the VHF radio transmits at 116.0 to 149.975 MHz, and the UHF radio transmits at 225.0 to 399.9 MHz. These radio transmitters produce a strong electric field (10 to 15 watts power output) within a narrow frequency band. A narrowband emission may not contribute significantly to a broadband signal, but harmonics produced by the emission may cause high readings in sensitive receivers. The receiver selectivity determines the amount of attenuation or rejection provided to off-tuned signals by the receiver (Duff, 1988). In this case, the lower frequency band sensor-receiver system is not able to attenuate the communication transmissions. The electric fields caused by off-tuned narrowband signals and harmonics do not have the same potential to cause interference in the frequency band because they do not produce the same power flux as a primary field.

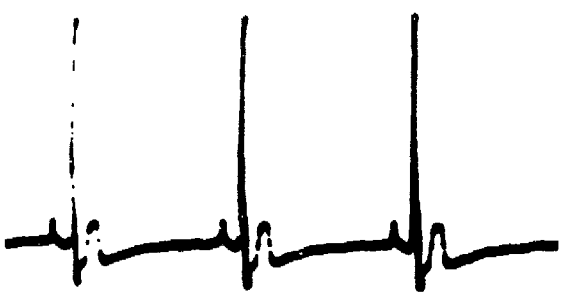
Several trends were noted in the measured electric fields of the helicopters tested. First, no specific area in any helicopter was found to have higher electric field strength in all operations. The homogeneity of the electric fields suggests that the in-flight testing of medical devices does not require a special test location to simulate the worst case. Second, the electric fields measured in the aircraft increased in intensity when aircraft systems and the engine operate. This suggests that some fields result from operation of the engine and generators in the aircraft. Third, the electric field measurements increase in intensity as the aircraft climbs. Since the monitored frequency bands include commercial broadcast and line-of-sight VHF communication frequencies, the aircraft is exposed to a stronger environmental electrical field at 1500-foot cruising altitude than on the ground.

Medical devices are tested in the laboratory at USAARL to determine their susceptibility to radiated emissions, as specified in MIL-STD-462, Notice 3, Method RS03. This involves observing the device for malfunctions while exposed to narrowband electromagnetic fields of 1 V/m from 10 kHz to 2 MHz, 5 V/m from 2 to 30 MHz, 10 V/m from 30 MHz to 2 GHz, and 5 V/m from 2 to 10 GHz.

The Physio-Control LIFEPAK® 8 monitor/defibrillator* has been evaluated in the laboratory and found susceptible to radiated emissions. Evidence of susceptibility included service alerts and erratic monitor displays and recordings. The frequency and electric field strengths where malfunctions occurred are listed below.

Frequency range	Minimum field causing malfunction
20 MHz - 20.8 MHz	1.50 - 2.00 V/m
30 MHz - 40.2 MHz	0.84 - 3.77 V/m

The LIFEPAK® 8 monitor was operated in the passenger compartment of the JOH-58A and JUH-1H helicopters with a test signal from a Valmet ECG Simulator*. When the FM transmitter was keyed (34.75 MHz), the electrocardiograph (ECG) baseline changed as noted in Figure 7. There was no change in the ECG signal when VHF or UHF transmitters were keyed. There was no interference when the LIFEPAK® 8 was tested in the JUH-60A helicopter. This example of electromagnetic interference in the LIFEPAK® 8 supports the laboratory's finding of radiated electric field susceptibility within the FM broadcast band, but not in VHF or UHF transmission bands for the device (Haun et al, 1991).



Normal ECG tracing

ECG tracing during FM transmission

Figure 7. Example of electromagnetic interference in an ECG monitor.

This study examined broadband radiated electric fields measured in U.S. Army helicopters. Narrowband radiated emissions or current conducted through a medical device's power cables or case also may cause the device to malfunction or fail. Each aircraft system and medical device must be checked to ensure electromagnetic compatibility.

Conclusions

The electric fields measured in this study were homogeneous and averaged less than 0.1 V/m in the ground environment. Electric fields measured in the aircraft were homogeneous and averaged less than 2 V/m except during aircraft radio transmissions. Electric fields increased in intensity as the helicopter climbed. This is most likely a result of increased exposure to commercial broadcast and other aircraft transmissions.

When the aircraft transmitted on FM, VHF, or UHF radios, the measurements in the 5 kHz to 3 MHz frequency band frequently exceeded the capacity of the receiver. This resulted from penetration of the higher frequency transmission signal and did not correlate with higher field strength when a medical device was introduced into the test environment.

The Physio Control LIFEPAK® 8 defibrillator/monitor showed a performance decrement when the JOH-58 or JUH-1H helicopter transmitted in the FM frequency band, but not during VHF or UHF transmissions. This correlates with the laboratory test findings for this device and models the electromagnetic interference that may be seen in operation aboard medical evacuation aircraft.

The electric field strengths measured in these aircraft and operating conditions may not be valid in other aircraft or flight areas. Narrowband emissions also must be considered since they can interfere with operation of medical devices. Tests to determine the susceptibility profile of a medical device and information about the electromagnetic fields in the operating area and aircraft are useful in predicting the potential for radiated field interference.

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Appendix A.

Aircraft radio equipment list

JUH-1H, SN 71-2003

Item	Description
ARC-51	UHF radio set
ARC 54	VHF-FM transmitter/receiver
AN/ARC-115	VHF-AM transmitter/receiver (VHF-AM and FM radio)
AN/ARC-83	ADF receiver
APX-72	Transponder

JOH-58A, SN 71-20778

Item	Description
AN/ARC-114	VHF-FM transmitter/receiver
AN/ARC-116	UHF radio set
AN/ARC-186	VHF-AM transmitter/receiver (VHF-AM and FM radio)
AN/ARN-89	ADF receiver
APX-72	Transponder

JUH-60A, SN 88-26029

Item	Description
AN/ARC-164	UHF radio set
AN/ARC-186	VHF-AM transmitter/receiver (VHF-AM and FM radio)
AN/ARN-89	ADF receiver
APN-209	Radar altimeter transmitter/receiver
APX-100	Transponder
ASN-128	Doppler navigation system

Appendix B.

List of Manufacturers

1. Amplifier Research, Aeritalia-Avionics
   160 School House Road
   Sounderton, PA 18934-9990

2. Holaday Industries, Inc.
   14825 Martin Drive
   Eden Prairie, MN 55344

3. Physio Control Corporation
   11811 Willows Road N.E.
   Redmond, WA 98052-1013

4. Valmedix ECG Simulator
   32303 Howard Street
   Madison Heights, MI 48071

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